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THE VERTICAL DISTRIBUTION AND MOVEMENTS OF THE SCHIZOPODA OF THE SAN DIEGO REGION

BY
CALVIN O. ESTERLY

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CALVIN O. ESTERLY

(Contribution from the Laboratory of Scripps Institution for Biological Research)

This is one of a series of papers, from the Scripps Institution for Biological Research, that deals with the behavior of plankton organisms as indicated by field data. Three publications have already appeared (Michael, 1911, and Esterly, 1912, and Esterly, 1914b) concerning the Chaetognatha, Copepoda, and Ctenophora. The facts upon which any conclusions may be based are obtained by first counting the individuals of different species in each successful surface and sub-surface haul. The hauls are then arranged according to months, time of day, temperature or salinity, and, since the number of animals taken in each set of hauls is known, it is possible to get some idea of the behavior of the organisms in nature, assuming that relative abundance with respect to various factors is a reliable criterion.

In this paper the surface, vertical closing, and horizontal closing net hauls are dealt with separately and no attempt is made to standardize the catches of one net with those of another for reasons given elsewhere (Esterly, 1912, p. 279). The terms used and explanations given by Michael (1911, p. 112) and by me (Esterly, 1912, p. 282) are applicable here. It is necessary to state, however, that I have not used any Nansen net hauls previous to number 1989 because the attempt was made to pull the net horizontally in those cases, and it seems better simply to omit the hauls from consideration. Furthermore, sub-surface hauls between numbers 2151 and 2278 do not enter into the tables because the Schizopoda were removed from the bottles

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by another person and there is some confusion in the data. In dealing with the surface collections for which the salinity is known no hauls have been used for which the salinity given is over 33.85, because of the likelihood of evaporation having taken place. In cases where the salinity is given for the beginning and the end of the haul, the average of the two values is used when the difference is 0.10 or less; when it is more than this the lower of the two values is taken. The reason for this procedure may be stated as follows: The accidental errors in determining salinities will not exceed 0.10 as a difference between two values for the same sample. While it is known that evaporation has occurred many times, it is assumed that the amount of evaporation may be neglected unless the salinity is very high indeed. Therefore, if two values differ by 0.10 or less, the correct value lies somewhere between them. Even if one sample has evaporated, the average of the two would be fairly close to the actual value. If, however, the difference between two values is more than 0.10 it seems plain that something more than accidental error is involved. The more probable effect in such cases is that of evaporation, and the lower value is then nearer the true average. If both samples have evaporated, it is still true that the average between the values, when the difference is not over 0.10, gives the more probable salinity. The salinities have been obtained from the manuscript, covering the hydrographic data for all the hauls, that is to be printed in the course of time, and values set down there as determined by the hydrometer and those marked "high" have been omitted. None of the data for hauls have been given here because all the data in the possession of the Institution are to be published separately in a subsequent volume of this series.

The species of schizopods whose distribution is to be studied are: *Euphausia pacifica* Hansen, *Nyctiphanes simplex* Hansen, *Thysanoessa gregaria* Sars, and *Nematoscelis difficilis* Hansen. For descriptions of these forms see Esterly (1914a). The first two species are by far the more abundant, but the others are found often enough to at least warrant their inclusion here.

The hauls considered in this paper extend from June 15, 1908, to April 17, 1913, inclusive, and with the exceptions already noted the hauls in the same month of the different years have been combined in each of the three tables that follow. The animals included in the enumerations are only such as have been certainly identified. While it is not likely that all are sexually mature, larvae and juvenals about which there is any uncertainty have been excluded. In all, the body

and appendages have assumed the form characteristic of the adults of the species. The successful surface hauls are entered in table 1, which follows.

TABLE 1

THE SUCCESSFUL SURFACE HAULS AND THE NUMBERS OF ANIMALS

Haul number	Euphausia pacifica	Nyctiphanes simplex	Thysanoessa gregaria	Nematoscelis difficilis
1582	8	....	....	....
1591	52	....	....	....
1682	109	....	....	....
2091	3	....	....	....
2123	1	....	....	....
2259	1	3	....	....
2271	....	4	....	....
2343	....	....	....	1
2476	15	....	....	....
2479	1	....	....	....
2639	....	....	5	....
2645	....	....	1	....
2674	....	....	1	....
2692	....	....	2	....
2906	....	1	....	....
2909	....	1	....	....
2930	....	57	....	....
2934	1	11	....	....
2960	....	63	....	....
2964	....	13	....	....
2975	5	....	....	....
2999	....	1	....	....
3011	....	255	....	....
3015	1	92	....	....
3051	....	8	....	....
3053	....	....	1	....
3064	....	1	....	....
3069	....	1	....	....
3088	....	45	....	....
3090	....	4	....	....
3101	....	1	....	....
3192	1	....	....	....
3288	....	....	....	1

In table 2, which follows, there are the successful hauls with the Kofoid, or horizontal closing, net.

TABLE 2

The Successful Hauls With the Horizontal Closing Net and the Numbers of Animals

Haul number	Euphausia pacifica	Nyctiphanes simplex	Thysanoessa gregaria	Nematoscelis difficilis
1620	1	....	....	....
1927	3	....	....	....
1929	5	....	....	....
1946	....	....	....	4
1947	....	....	....	1
1965	1	....	....	....
1970	....	....	1	....
1971	2	....	....	....
1972	2	....	....	....
1978	11	....	....	....
1979	....	....	....	1
2891	6	....	....	....
2902	....	....	....	1
2903	....	....	....	1
2905	....	....	....	1
2913	2	....	....	....
3027	....	41	....	....
3028	....	58	....	....
3030	....	12	....	....
3031	....	5	....	....
3033	....	22	....	....
3034	....	120	1	....
3035	....	8	....	....
3036	3	....	....	....
3037	1	....	....	....
3038	215	157	....	....
3039	113	144	....	....
3040	6	50	....	....
3041	4	7	....	....
3043	....	1	....	....
3044	....	6	2	....
3046	....	11	2	....
3047	....	7	....	....
3048	....	14	....	....
3049	10	....	....	....
3050	10	....	....	....
3289	....	....	....	5
3291	....	....	....	6

Table 3, which follows, contains the successful hauls made with the Nansen, or vertical closing, nets.

TABLE 3

THE SUCCESSFUL HAULS WITH THE VERTICAL CLOSING NETS AND THE NUMBERS OF ANIMALS

Haul number	Euphausia pacifica	Nyctiphanes simplex	Thysanoessa gregaria	Nematoscelis difficilis
2017	12	....	....	....
2018	12	....	....	....
2019	4	....	....	....
2020	80	....	....	....
2022	42	....	....	....
2023	6	....	....	....
2031	167	....	....	3
2032	142	....	....	....
2036	4	....	....	....
2038	1	....	....	....
2048	25	....	....	....
2052	7	....	....	1
2067	34	....	....	4
2068	78	....	....	2
2069	16	....	....	....
2073	25	....	....	....
2074	....	....	....	1
2081	12	....	....	....
2089	35	....	....	....
2090	41	....	....	....
2094	15	....	....	....
2095	140	....	....	....
2100	35	....	....	....
2104	27	....	....	....
2108	3	....	....	....
2112	6	....	....	....
2119	39	....	....	1
2120	10	....	....	....
2121	12	....	....	....
2122	14	....	....	....
2130	13	....	....	....
2131	4	....	....	....
2133	14	....	....	....
2134	4	....	....	1
2135	6	....	....	1
2139	5	....	....	....
2142	1	....	....	....
2144	6	....	....	....
2371	1	....	....	....
2387	1	....	....	....
2626	1	....	....	....
2807	2	....	....	....

TABLE 3—(*Continued*)

Haul number	Euphausia pacifica	Nyctiphanes simplex	Thysanoessa gregaria	Nematoscelis difficilis
2933	----	7	----	----
2937	5	----	----	----
2938	5	----	----	----
2963	----	2	----	----
2968	1	----	----	----
3018	1	----	----	----
3020	----	1	----	----
3025	1	1	----	----
3056	1	----	----	----
3060	----	----	1	----
3093	2	----	----	----
3103	1	----	----	----
3137	1	----	----	----
3195	2	----	----	----
3199	1	----	----	----
3202	2	----	----	----
3219	1	----	----	----
3272	----	----	----	1

It is rather surprising how little is known about the behavior of the schizopods, although the group is one of the best known among the Crustacea from the systematic side. There is a short paper by Fowler (1905) concerning the movements of these animals, and Holt and Tattersall (1905) briefly discuss behavior. Both these papers deal only with field data, and so far as I know there are no other references on the subject.

In considering the distribution of the Schizopoda it is necessary to keep in mind that their eyes are highly developed and apparently very serviceable organs. Consequently the possibility deserves to be considered that large catches, at night, for example, are obtained because the animals cannot see the nets, while during the day they could avoid capture. The organisms are powerful swimmers and probably active enough to get out of the way of the slow-moving surface nets at least. It may be said here that Fowler inclines to the view that facts appear which cannot be accounted for by supposing that the animals see the nets, and I concur in this for reasons that will appear later.

The question of seasonal occurrence is one that always has to be considered, and in table 4, which follows, there are set down the surface hauls by months, together with the number of hauls (total and successful) and the number of animals of each species in each month. There appears also the haul frequency for every month.

TABLE 4

NUMBER OF HAULS, HAUL FREQUENCY AND NUMBERS OF ANIMALS FOR EACH MONTH; SURFACE COLLECTIONS

Month	Total Hauls	Succ. Hauls	Freq.	Numbers of animals: Euphausia pacifica	Nyctiphanes simplex	Thysanoessa gregaria	Nematoscelis difficilis	Total
Feb.	17	0	0	0	0	0	0	0
March	30	3	10	4	0	0	1	5
April	13	1	8	1	0	0	0	1
June	83	7	8	125	0	0	1	126
July	40	1	2.5	60	0	0	0	60
August	42	4	9	0	10	9	0	19
Sept.	6	0	0	0	0	0	0	0
Oct.	20	1	5	0	2	0	0	2
Nov.	6	2	33	1	68	0	0	69
Dec.	17	13	77	6	484	1	1	492

Schizopods were found in 32 of the 274 surface hauls. This is the smallest proportion of successful hauls for any of the groups of organisms that have been studied here. The chaetognath *Sagitta bipunctata* was found in 70 per cent of the surface hauls (Michael, 1911, p. 115), the copepod, *Calanus finmarchicus* in 57 per cent (Esterly, 1912, p. 281) and the ctenophore *Pleurobrachia bachei* in 25 per cent of all the hauls (Esterly, 1914b, p. 25). In contrast to such figures as these, the schizopods *as a group* were found in but 12 per cent of the surface hauls.

As shown in the table, *Euphausia* was far more abundant at the surface in June and July, and *Nyctiphanes* in November and December, than at any other season of the year. The frequency is exceedingly low for all months except November and December, when the occurrence of *Nyctiphanes* makes the number of successful hauls large by comparison. The question at once arises, how much dependence can be placed on a study of this sort when it has to be based on such a small number of hauls that obtained animals? The answer is not easy to give. We must use what evidence we have, and it may reasonably be urged that the *proportion* of successful and unsuccessful hauls is as large now as it ever will be, since our collections extend over different periods in five years. More collections will undoubtedly increase the number of animals obtained and perhaps distribute the hauls more evenly as to season or time of day, but it is not to be expected that the frequency of occurrence will be raised.

The total of animals obtained among the Schizopoda, at the surface. is small, also, when compared to the numbers of the other groups. About 39,000 specimens of the two commoner chaetognaths were taken at the surface (Michael, 1911, pp. 115, 145). The two most abundant copepods appeared in the number of about 23,000 (Esterly, 1912, p. 281), and about 7200 specimens of *Pleurobrachia* were obtained (Esterly, 1914b, p. 25). As can be seen in table 4, approximately 750 schizopods were present in the surface hauls.

Table 5, dealing with the hauls made with the Kofoid horizontal closing net and with the vertical net, is similar to table 4 in arrangement.

TABLE 5

Number of Hauls, Haul Frequency and Numbers of Animals for Each Month; Horizontal and Vertical Closing Nets

Month	Total Hauls	Succ. Hauls	Freq.	Numbers of animals: Euphausia pacifica	Nyctiphanes simplex	Thysanoessa gregaria	Nematoscelis difficilis	Total
I. Horizontal Nets								
Feb.	0	0	0	0	0	0	0	0
March	8	2	25	0	0	0	11	11
April	19	0	0	0	0	0	0	0
June	23	1	4	1	0	0	0	1
July	47	0	0	0	0	0	0	0
August	2	0	0	0	0	0	0	0
Sept.	8	2	25	8	0	0	0	8
Oct.	25	3	12	8	0	0	1	9
Nov.	16	10	65	16	0	1	8	25
Dec.	23	20	87	362	663	5	0	1030
II. Vertical Nets								
Feb.	63	3	5	87	0	0	0	87
March	105	27	26	880	0	0	13	893
April	46	14	30	137	0	0	4	141
June	205	3	1.5	3	0	0	0	3
July	9	0	0	0	0	0	0	0
August	68	0	0	0	0	0	0	0
Sept.	0	0	0	0	0	0	0	0
Oct.	38	1	3	2	0	0	0	2
Nov.	19	3	16	10	7	0	0	17
Dec.	90	9	10	7	4	1	0	12

Table 5 does not give the distribution by depths, but shows only the catches of the nets for each species and the totals during each month. The two parts of the table are in general agreement in that hauls during the warmer months (June through October) are notably

less successful than those during the rest of the year. There are some curious discrepancies, however, between the parts of the table. In part I, *Nyctiphanes* appears only in December hauls, but in fairly large numbers, while with the vertical nets (part II) only eleven animals were captured. *Euphausia* was most abundant in December in the horizontal nets and in March in the vertical nets.

Table 5 agrees with table 4 in regard to the seasonal occurrence of *Nyctiphanes,* but *Euphausia* was most abundant in June and July in the surface collections (table 4) instead of in the spring or fall, as in the hauls with closing nets (table 5).

As far as our data go at the present time, the Schizopoda are shown to be more abundant at all levels during the colder portion of the year (November through April), as is indicated in the following summary of tables 4 and 5. The season of colder water is referred to as "winter", for convenience, and is contrasted with the "summer", or warmer months.

A total of 191 hauls in summer at the surface	took	207	specimens
A total of 83 hauls in winter at the surface	took	567	specimens
A total of 104 hauls in summer with the Kofoid net	took	18	specimens
A total of 67 hauls in winter with the Kofoid net	took	1066	specimens
A total of 320 hauls in summer with the Nansen net	took	5	specimens
A total of 323 hauls in winter with the Nansen net	took	1150	specimens

Since there is, apparently, such a sharply defined seasonal occurrence, we may consider the distribution of *Euphausia* and *Nyctiphanes* (as the more important species) at the surface with regard to temperature, since that factor varies noticeably with the season. As a matter of convenience, the distribution of the surface hauls, in water of different temperatures, is given by months in table 6.

TABLE 6

DISTRIBUTION OF SURFACE HAULS BY MONTHS ACCORDING TO DIFFERENT TEMPERATURES

Temperature	Feb.	March	April	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
14° and less	5	0	2	0	0	0	0	0	0	1	8
14°.1–15°	3	21	5	0	0	0	0	0	0	7	36
15°.1–16°	2	5	1	0	0	1	0	0	1	4	14
16°.1–17°	0	1	4	25	4	2	1	0	3	5	45
17°.1–18°	0	0	0	27	1	0	0	0	2	0	30
18°.1–19°	0	0	0	11	9	0	3	2	1	0	26
19°.1–20°	0	0	0	10	3	9	1	13	0	0	36
20°.1 and more	0	0	0	0	9	23	1	2	0	0	35
Total	10	27	12	73	26	35	6	17	7	17	230

As shown in table 4, *Euphausia* was taken in greater numbers at the surface in June and July, and a consideration of its distribution as regards temperature should deal with those hauls. Table 7, however, which follows, includes all the so-called summer hauls. There are but five successful hauls, and it is very questionable whether the results of the tabulation can be regarded as having much weight. The table is presented for what it is worth.

TABLE 7

Distribution of *Euphausia* During the Summer, at the Surface, With Regard to Different Temperatures, None Below 15°.1

Temperatures	No. of hauls: Total	Success.	No. of hours: Total	Success.	No. of animals: Total	Per hour	Frequency: Haul	Time
1. 15°.1–16°	1	0	0.3	0	0	0	0	0
2. 16°.1–17°	32	1	23.5	0.6	109	4.6	3	3
3. 17°.1–18°	28	2	23.2	1.5	16	0.7	7	6
4. 18°.1–19°	25	0	17.1	0	0	0	0	0
5. 19°.1–20°	36	0	28.3	0	0	0	0	0
6. 20°.1 and more	35	2	23.1	0.8	60	2.6	5.5	3

It is shown in the table that the likelihood of the capture of many specimens below 16°.1 is exceedingly slight during the summer, because the number of hauls is so small, while, as far as the number of hauls is concerned, the chances are about equal above 16°.1. As the table stands, the interpretation to be given is that *Euphausia* does not exhibit marked behavior toward temperature during the summer. It has been shown in table 5 that *Euphausia* is obtained in greater numbers with the Kofoid net in December, when the temperature must be below 17° (see table 6) since sub-surface temperatures are not higher than the surface temperatures. This schizopod is more abundant in the Nansen hauls in March (table 5, part II) and sub-surface temperatures should be less than 16° during that month (see table 6). If it may be assumed that the results of surface collecting are not to be entirely disregarded on account of the few successful hauls, temperature is not a factor of much importance in the determination of the surface distribution of *Euphausia*.

The case with *Nyctiphanes* appears to be different, on account of a larger number of successful hauls as well as because there is a larger number of animals. Table 8 considers the winter hauls and the occurrence of *Nyctiphanes* in them according to temperature.

TABLE 8

DISTRIBUTION OF *Nyctiphanes* DURING THE WINTER, AT THE SURFACE, WITH REGARD TO DIFFERENT TEMPERATURES, NONE ABOVE 19°.

Temperatures	No. of hauls: Total	Success.	No. of hours: Total	Success.	No. of animals: Total	Per hour	Frequency: Haul	Time
1. 14° and less	8	0	7.4	0	0	0	0	0
2. 14°.1–15°	36	5	34.75	4.7	52	1.5	14	14
3. 15°.1–16°	13	2	13.6	3.1	19	1.4	15	22
4. 16°.1–17°	12	5	13.	6.35	418	32.1	42	49
5. 17°.1–18°	2	0	1.2	0	0	0	0	0
6. 18°.1–19°	1	0	0.37	0	0	0	0	0

The results arrived at in the preceding table seem to be worthy of confidence. The optimum temperature for *Nyctiphanes* is clearly between 16°.1 and 17°. It may not be significant that no specimens were obtained in water above 17°, because the hauls are so few, but it may at least be regarded as true that the species is not found at temperatures below 14°.1 on the surface.

The effect of salinity on the distribution of the schizopods warrants only brief mention. There are four surface hauls out of a total of 135, for which the salinity is known, that obtained *Euphausia* during the summer. The salinities lie between 33.66 and 33.70, and 177 of the 185 animals obtained during the summer were in those four hauls. It may be suggested, therefore, that the optimum salinity at the surface is within the limits mentioned.

The salinity is given for 22 surface hauls made during the winter, but only one of these hauls obtained *Nyctiphanes;* the salinity is set down as 33.61. There were 13 animals in the haul.

Another factor, in addition to temperature and salinity, that may influence the distribution of organisms at the surface is light. It is possible to gain some idea of the effect of light by comparing the numbers of animals taken at different times of day. In accordance with the plan followed in other papers of this character (Michael, 1911, Esterly, 1912), the day is divided into twelve two-hour periods, and the results for *Euphausia* with regard to the summer hauls are set down in table 9, which follows.

It will be noted in the table that no animals were obtained from 4 a.m. to 6 p.m. (lines 12–6). From 6 p.m. to 4 a.m. there are six successful hauls in 46, with a total of 185 animals. The time of greatest abundance is from 6 to 8 p.m. (line 7). The results do not indicate that there may be a diurnal migration, and our data for the summer

TABLE 9

Distribution of *Euphausia* at the Surface, by Two-Hour Periods Through the Day, for the Summer Months

Time of Day	No. of hauls: Total A	No. of hauls: Success. B	No. of hours: Total C	No. of hours: Success. D	No. of animals: Total E	No. of animals: Per hour F	Frequency: Haul G	Frequency: Time H
A.M.								
1. 6– 8	29	0	20.4	0	0	0	0	0
2. 8–10	24	0	22.3	0	0	0	0	0
3. 10–12	19	0	11.5	0	0	0	0	0
P.M.								
4. 12– 2	16	0	11.0	0	0	0	0	0
5. 2– 4	10	0	5.25	0	0	0	0	0
6. 4– 6	10	0	6.6	0	0	0	0	0
7. 6– 8	26	2	15.2	0.8	161	10.6	8	5
8. 8–10	7	1	3.8	0.4	8	2.1	14	11
9. 10–12	1	0	1.1	2.8	0	0	0	0
A.M.								
10. 12– 2	2	0	0	0	0	0	0	0
11. 2– 4	10	3	8.0	3	16	2.0	30	37
12. 4– 6	35	0	26.0	0	0	0	0	0

months alone do not provide for judging whether it takes place or not. The Kofoid nets took only 17 *Euphausias* during the summer, while the Nansen nets took five, and the surface nets obtained very few animals during the months when the surface net captured many. It is possible to show, however, that there is some evidence for the occurrence of vertical movements, in the results of collecting with the Kofoid and Nansen nets. Table 10, which follows, treats of the distribution of *Euphausia* during the winter, as shown by collections with the Kofoid net.

TABLE 10

Distribution of *Euphausia* at Different Levels and at Different Times of Day as Shown by the Kofoid Net; Winter Months

Depth in meters	A 6 A.M.–6 P.M 9–100 1	101–200 2	201–400 3	401+ 4	B 2 A.M–6 A.M. 9–100 1	101–200 2	201–400 3	401+ 4
1. Total hauls	50	17	13	7	3	0	0	0
2. Successful hauls	2	2	4	1	3	0	0	0
3. Total hours	9.0	3.6	2.9	1.7	0.65	0	0	0
4. Successful hours	0.65	0.4	0.9	0.25	0.65	0	0	0
5. Total animals	4	11	28	1	334	0	0	0
6. Animals per hour	0.3	3	10	0.6	515	0	0	0
7. Haul frequency	4	12	31	14	100	0	0	0
8. Time frequency	7	11	31	15	100	0	0	0

There were no hauls made between 6 p.m. and 2 a.m., so we are unable to account for the animals during that time, at least as far as the horizontal hauls are concerned. As the table stands, however, it contains some facts that are worth noting. It is to be suggested that table 10 is to be interpreted as showing that *Euphausia* performs vertical migrations. In the first place, more animals are obtained per hour between 200 and 400 meters during the day than above that level (section A, columns 1–3, line 6). Furthermore, as shown in section B, column 1, the level above 100 meters is densely populated in the early morning, whereas only four animals were taken there in 50 day hauls (section A, column 1, line 5). As a matter of fact, all the hauls set down in section B, column 1, were made between 18 and 37 meters. It may be objected, of course, that there might have been about as many animals between 9 and 100 meters from 6 a.m. to 6 p.m. as there were from 2 a.m. to 6 a.m., but they were not captured at that level during the day because they were able to see the nets and avoid them. It must be admitted that this is possible and that our data from the hauls with the Kofoid net do not show that it is not likely. The data are deficient in that there are no hauls below 100 meters between 2 and 6 a.m. If the increase in the hourly average in column 1, section B, over that in column 1, section A, is due to the migration of animals from below into the upper level we should expect that at the time of the *increase* above 100 meters, the population below that mark would show a *decrease*. Obviously, it is not possible to show this in the present state of our records. For all we can tell, there might be an *increase* in the population below 100 meters in section B of the table, instead of the decrease necessary to establish the fact of upward migration. I believe, nevertheless, that the results indicated in table 10 are to be looked upon as due to a vertical movement of the animals. This view is strengthened by an examination of the results of the collections with the Nansen nets. As shown in table 4, only the winter hauls are worth consideration.

There were no hauls between 10 p.m. and 2 a.m., but the time from 6 to 10 p.m. is covered by thirteen hauls; this period was not covered in table 10. The depths in tables 10 and 11 correspond as nearly as possible, but it will be noted that there are considerable differences. The day plurimum as shown by the Nansen hauls is located between 365 and 460 meters (table 11, section A, column 4, line 4); there were fifty times as many animals obtained per meter between 460 and 365

TABLE 11

Distribution of *Euphausia* at Different Levels and at Different Times of Day as Shown by the Nansen Net; Winter Months

	A 6 A.M.–6 P.M.					B 6 P.M.–10 P.M.					C 2 A.M.–6 A.M.				
Depth in meters from	137	275	365	460	550	137	275	365	460	550	137	275	365	460	550
Depth in meters to	0	185	275	365	460	0	185	275	365	460	0	185	275	365	460
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1. Total hauls	186	12	6	8	5	7	4	2	0	0	91	4	2	1	1
2. Successful hauls	7	4	3	4	3	5	4	2	0	0	12	3	2	1	1
3. Total animals	6	29	164	293	76	190	171	53	0	0	65	36	18	6	5
4. Animals per m.	.06	0.3	1.8	3.	0.7	1.4	1.9	0.6	0	0	.47	0.4	0.2	.06	.05
5. Haul frequency	0.3	33	50	50	60	71	100	100	0	0	13	75	100	100	100

meters as above 137 meters. The depth of the greater abundance for daylight as shown in table 10 corresponds fairly well with that shown in table 11, but it should be noted that the averages in line 6 of table 10 are *per hour,* while in line 4 of table 11 they are *per meter.*

In section B of table 11, columns 1, 2, there is a large increase in the number of animals taken, per meter of hauling, over the numbers set down in the corresponding columns in section A. It is important to note, furthermore, that the meter average in column 3 of section B is but one-third as large as that in column 3 of section A. I believe that this means that there is an actual decrease, after dusk, in the number of animals below 275 meters, and that the increase indicated in columns 1 and 2, section B, is due to migration of animals into those levels from below. While there is some reason for saying that animals *might* see the nets during the day at the surface, that will not explain the *decrease at night* in deep water. If the organisms are taken in larger numbers only when they cannot see the nets, there is no reasonable explanation for the facts shown in sections A and B of the preceding table.

The records in section C of table 11 as compared with those in A and B are indicative of the *downward* movement that we should expect if there is the upward movement at an earlier time. The meter average in columns 1 and 2 of section C is considerably larger than that in section A, but smaller than that in section B, and the same relation holds between the frequencies. In column 3, however, the average per meter is larger in section A than that in the others and that in section B exceeds that in section C. I believe that these relative figures mean that the movement toward deeper water begins before 2 a.m., and is not completed until after 6 a.m.

A consideration of the occurrence of *Nyctiphanes* at the surface must be confined to winter hauls, as is shown in table 4. The animals were obtained only in November and December, but it seems fair to consider all the winter months together. This is done in table 12.

The table shows that *Nyctiphanes* is overwhelmingly more abundant at the surface between 4 and 6 a.m. (line 12, columns E and F). We are not justified in assuming that that period really represents the time of the surface plurimum, since it *might* occur during one of the periods when no collecting was done. The table does not suggest, in itself, that the organisms perform periodic vertical migrations, but there is some evidence of this in the data concerning the hauls with

TABLE 12

Distribution of *Nyctiphanes* at the Surface, by Two-Hour Periods Through the Day, Winter Months

Time of Day	No. of hauls: Total A	Success. B	No. of hours: Total C	Success. D	No. of animals: Total E	Per hour F	Frequency: Haul G	Time H
A.M.								
1. 6– 8	17	2	16.5	1.25	11	1.4	12	7
2. 8–10	19	4	14.15	3.17	4	0.7	21	22
3. 10–12	11	0	7.9	0	0	0	0	0
P.M.								
4. 12– 2	10	0	8	0	0	0	0	0
5. 2– 4	5	0	4	0	0	0	0	0
6. 4– 6	7	0	5.7	0	0	0	0	0
7. 6– 8	4	0	4	0	0	0	0	0
8. 8–10	0	0	0	0	0	0	0	0
9. 10–12	0	0	0	0	0	0	0	0
A.M.								
10. 12– 2	0	0	0	0	0	0	0	0
11. 2– 4	2	0	2.8	0	0	0	0	0
12. 4– 6	12	7	13.4	7.1	537	40.	58	53

the Kofoid net. These data are considered in table 13, which follows; it deals with winter hauls necessarily, since no animals were obtained except in December (table 5).

TABLE 13

Distribution of *Nyctipnanes* at Different Levels and at Different Times of Day as Shown by the Kofoid Net; Winter Months

Depth in meters	A 6 A.M.–6 P.M. 9–100	101–200	201–400	401+	B 2 A.M.–6 A.M. 9–100	101–200	201–400	401+
	1	2	3	4	1	2	3	4
1. Total hauls	50	17	13	7	3	0	0	0
2. Successful hauls	8	3	2	0	3	0	0	0
3. Total hours	9.	3.6	2.9	1.7	.65	0	0	0
4. Successful hours	1.8	0.7	1.	0	.65	0	0	0
5. Total animals	141	156	15	0	351	0	0	0
6. Animals per hour	16.	43.	5.2	0	542	0	0	0
7. Haul frequency	16	17	15	0	100	0	0	0
8. Time frequency	20	20	35	0	100	0	0	0

The preceding table is similar to table 10 for *Euphausia,* and it is of interest to compare the two. *Nyctiphanes* is shown to be more abundant, during the day, at depths between 101 and 200 meters, while *Euphausia* is more abundant below 200 meters (compare section A, line 6 in tables 10 and 11). *Nyctiphanes* is much more abundant

above 100 meters than is *Euphausia*. Both forms show a great increase in numbers between 9 and 100 meters during the period from 2 a.m. to 6 a.m. Nothing can be added here to what was said above concerning the behavior of *Euphausia* as shown by the Kofoid net. Though this distribution *suggests* that diurnal migration takes place, it can not be shown more certainly, because we know nothing about the occurrence of the animals at any depth from 6 p.m. to 2 a.m.

Nyctiphanes appeared in four Nansen hauls out of 643; the successful ones were in November and December, and they contained eleven animals. These four hauls were all made above 137 meters and between 4 and 6 a.m. These results agree, as far as they go, with those of the Kofoid nets, but the puzzling question is, why were there so few animals in the Nansen hauls when these are compared with the other hauls? There is evidence in table 11 that the animals were present at depths above 200 meters in fairly large numbers, but that would never be shown by the Nansen hauls alone. The answer to the question can not be given at this time. In table 12 it was shown that *Nyctiphanes* is more abundant on the surface between 4 and 6 a.m., and in table 8 it appears that the optimum temperatures lie between 14°.1 and 17°. It is desirable to inquire whether there is a relation between the time of day and the surface temperatures in regard to the abundance of the organisms. Table 14 contains the data for this.

TABLE 14

SURFACE DISTRIBUTION OF *Nyctiphanes* DURING THE WINTER, ACCORDING TO THE TIME OF DAY BUT WITHIN THE TEMPERATURES 14°.1–17°

A.M. Time of Day	No. of hauls: Total	No. of hauls: Success.	No. of hours: Total	No. of hours: Success.	No. of animals: Total	No. of animals: Per hour	Frequency: Haul	Frequency: Time
1. 6– 8	11	4	14	4.1	103	7.4	18	30
2. 8–10	15	4	10.3	3.2	4	0.4	20	32
3. 10– 2 (16 hrs.)	25	0	21.9	0	0	0	0	0
4. 2– 4	1	0	1.6	0	0	0	0	0
5. 4– 6	9	6	11.6	6.7	382	33.0	66	58

The table is self-explanatory, and gives reason for believing that, even if hauls are made at temperatures between 14°.1 and 17°, they will probably obtain small numbers of animals unless they come between 4 and 8 a.m., while the likelihood of large catches is increased between 4 and 6 a.m. The table shows, furthermore, that the lack of success during the sixteen hours from 10 a.m. to 2 a.m. is not due

altogether to prevalence of unfavorable temperatures. While the *relative* number of hauls for those hours is smaller than for any other time, it does not seem very likely that more hauls would lead to greater success in collecting. If hauls are made between 4 and 8 a.m. and at temperatures ranging from 14°.1 to 17°, fairly large numbers of animals are obtained and a few less than half the hauls are successful.

The relation between salinity and other factors as affecting surface distribution cannot be determined because the salinity is known for but one of the surface hauls that obtained *Nyctiphanes* during the winter.

Since *Euphausia* was obtained in only four surface hauls, in large numbers, it seems hardly worth while to consider the relation between the abundance of this animal and combinations of factors as was done for *Nyctiphanes* in table 14. It may be worth while to state, however, that at optimum salinities (33.66–33.70) during the summer, about seven times as many *Euphausias* are obtained on the surface per hour when the temperature ranges from 16°.1–17° as at any temperatures (of those indicated in table 6) above 17°. Since the above maximum for *Euphausia* is based upon one successful haul, there may be considerable doubt as to whether it even deserves mention.

The above consideration of the occurrence and distribution of *Euphausia* and *Nyctiphanes* contains facts as they are derived from our data. It has been shown that *Euphausia* is more abundant at the surface during June and July, while *Nyctiphanes* appears in larger numbers during November and December (table 4). Those winter months are the more favorable for both species, so far as the collections with the Kofoid net are concerned (table 5, section A). The hauls made with the Nansen nets show that *Euphausia* is more abundant in March and April, *Nyctiphanes* in November and December, but it should be noted that only eleven animals of the latter species were obtained in all the vertical closing hauls (table 5, section II).

The general statement that is justified as to seasonal distribution of the two commoner schizopods is: The number of animals and the number of successful hauls is considerably larger during the colder months (November to April).

Although *Euphausia* was more abundant during the summer, and *Nyctiphanes* during the winter, the optimum surface temperature for both lies between 16°.1 and 17° (tables 7 and 8).

Euphausia was not taken at the surface by day during the summer (table 9), and the number of animals per hour at night is largest

between 6 and 8 p.m. *Nyctiphanes* was found at the surface during the winter, in larger numbers from 4–6 a.m., though a few animals occurred as late as 10 a.m. (table 12).

During the day in the winter months *Euphausia* appears to be more abundant between 200 and 400 meters (table 10) and *Nyctiphanes* between 101 and 200 meters (table 13), as shown by the collections with the Kofoid net. From 2–6 a.m. the average capture per hour between 9 and 100 meters is very greatly increased over that between 6 a.m. and 6 p.m. No hauls were made during the early morning at depths below 100 meters, but what has been pointed out is some indication that there is an upward movement of the animals at night.

The collections with the Nansen nets show that during the winter and by day *Euphausia* is more abundant between 460 and 365 meters (table 11, section A, column 4, line 4). From 6 to 10 p.m. the meter average is higher, between 275 and 185 meters, and it is about six times as great then as it is from 6 a.m. to 6 p.m. at that level, while the evening meter average between 137 meters and the surface is twenty-five times that during the day. At the same time (nightfall) that the abundance increases above 275 meters, it decreases to a marked degree as far down as 365 meters when compared with the day average. This manner of occurence indicates that there is an upward movement of the animals at dusk or soon after. The meter averages at depths down to 365 meters are lower between 2 and 6 a.m., than at corresponding levels from 6–10 p.m., but above 137 meters the average is notably higher in the early morning than by day. This suggests that the downward movement begins, roughly, between 10 p.m. and 2 a.m. The small number of specimens of *Nyctiphanes* obtained with the Nansen nets prevents an analysis of the occurrence of this form.

The general indication for both *Euphausia* and *Nyctiphanes* is that the animals do not remain during the night at the depths where they are more abundant by day. This is in line with the suggested results obtained by Holt and Tattersall (1905) and Fowler (1905). These authors show, for several genera, that there is a rather strong probability that the animals move up at night and descend during the day; at the same time they are careful to recognise the possibility that the failure to capture as many animals at or near the surface by day as by night may be due to actual avoidance of the nets. The investigators named do not admit, however, that their results can all be explained on the "avoidance" basis.

It would be injudicious to attempt to assign causes for the behavior that is suggested by the preceding facts, but it may be well to point out some of the more general applications that the facts bring up. In the first place, there is reason for thinking that the Schizopoda fall into line with other organisms in the matter of vertical migration. This phenomenon is well marked among the Chaetognatha (Michael, 1911), Ostracoda (Fowler, 1909), and Copepoda (Esterly, 1912). It is of interest, therefore, to add to this list the relatively highly organized Schizopoda, though it must be admitted that the evidence regarding their movements is not as convincing as that for the other groups.

In this connection the recent paper of Franz (1913) may be noted. This author gives it as his opinion (p. 271) that it is doubtful if periodic migrations take place. It seems that he must have failed to grasp the evidence brought forward by the investigators just named. Franz has the notion, as can be seen on page 272 of his article, that this evidence is based upon the relative abundance of the animals in night and day *surface* hauls. This is not the case, for Michael, Fowler and I have shown that at the times the increase takes place in upper water there is a corresponding decrease in deeper water. If the conclusion that periodic migrations occur were based only on surface hauls, it might properly be discredited; as it is, however, the weight of evidence favors that view. Furthermore, Franz (1913, p. 272) states that "it seems entirely natural" (to him) that the animals see the nets by day and escape them, but can not do so at night, and this accounts for the difference between the day and night catches. It should be shown, of course, as it has not been, that the organisms *actually do* escape capture by means of the sense of sight. It is true that the schizopods probably could see the surface nets, and that even the copepods and chaetognaths *might,* but this criticism certainly has no bearing in the case of some of the ostracods which *have no eyes.*

The second general application that may be mentioned is the evident specific *behavior* shown in the cases of *Euphausia* and *Nyctiphanes.* A similar condition has been noted by Michael (1911, p. 160) for the chaetognaths, and I called attention to it, as shown in the copepods (Esterly, 1912, p. 328). Indications of this occur also among the Ctenophora (Esterly, 1914b, p. 35).

In concluding this paper it may be well to mention what is known about the occurrence of *Thysanoessa* and *Nematoscelis.* Seventeen specimens of the former were obtained in *all* the hauls, and thirty-nine of the latter (see tables 4 and 5).

Nine of the ten specimens of *Thysanoessa* taken at the surface were obtained in August, and eight of the nine appeared in hauls made between 4 and 6 a.m. The temperatures of the successful hauls range from 19°.8 to 20°.1; these are two or three degrees higher than the optimum temperatures for *Euphausia* and *Nyctiphanes*.

Thysanoessa appeared in the Kofoid nets only in November and December; there were six animals and five of them were taken at depths between 55 and 73 meters, while one was in a haul at 185 meters. All of these are day hauls and it seems, therefore, that this species does not go as deep as the two commoner ones. One specimen was obtained in the Nansen nets, in December, and in a haul from 46 to 37 meters.

Two specimens of *Nematoscelis* were obtained at the surface; one in June and one in December. Twenty animals were taken with the Kofoid net, none above 73 meters nor below 185 meters; eleven of the specimens came from between 137 and 185 fathoms. All but one of the animals were obtained during the winter. The successful hauls with the Nansen nets were made in March and April. Only one of the seventeen specimens was obtained from above 185 meters, while eleven came from below 365 meters. This range is much below that shown by the Kofoid nets.

SUMMARY

1. The Schizopoda as a group are found in smaller numbers and less frequently than the Chaetognatha, Copepoda, or Ctenophora.

2. The Schizopoda are obtained in much greater numbers during the colder season of the year (November–April), and especially in December, February and March.

3. *Euphausia pacifica* Hansen and *Nyctiphanes simplex* Hansen are the more abundant species, and the ones whose behavior is better known. With regard to these two forms, we find:

(*a*) *Euphausia* is more abundant at the surface in June and July, while *Nyctiphanes* is more abundant during November and December.

(*b*) Both are obtained with the Kofoid net in larger numbers in December; these hauls are practically unsuccessful during the other months.

(*c*) The Nansen nets obtained over 1100 specimens of *Euphausia*, and more than 1000 of these in March and April, but only eleven specimens of *Nyctiphanes* were present in the entire series of Nansen hauls.

(*d*) The center of the sub-surface region where *Euphausia* is more abundant by day, as shown by the winter hauls, appears to be at 300 meters, while *Nyctiphanes* seems to center at 150 meters during the day.

(*e*) There is some evidence that both *Euphausia* and *Nyctiphanes* perform diurnal migrations.

(*f*) *Euphausia* is more abundant at the surface in the summer, and *Nyctiphanes* in the winter, but both are found in larger numbers (in the respective seasons) when the surface temperature ranges from 16°.1 to 17°.

(*g*) *Nyctiphanes* is found in much larger numbers (at the surface and during the winter) between 4 and 6 a.m. than at any other period of the day. No specimens were found between 10 a.m. and 4 a.m. The time of greater abundance of *Euphausia* at the surface (during the summer) is from 6 to 8 p.m., but this appears from only six successful hauls.

(*h*) A comparison of the manner of occurrence of *Euphausia* with that of *Nyctiphanes* suggests that species may be characterized by behavior as well as by structure.

Occidental College, Los Angeles, California.

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